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Miniature Circulating Systems for Small Laboratory Aquaria

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(Plates I & II; Text-figures 1-5)

Introduction

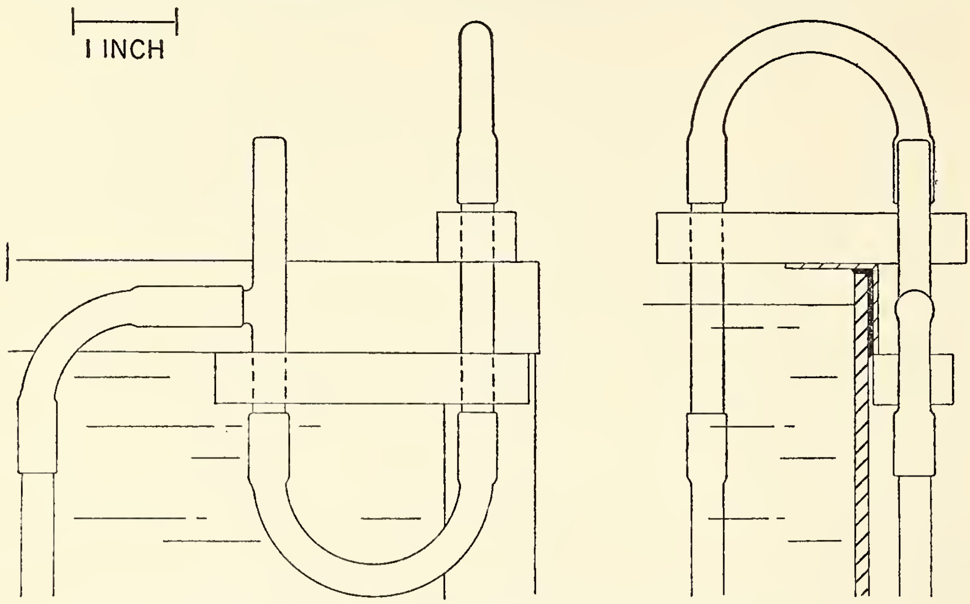
Because of the requirements of certain experiments it became necessary to establish various small, but fully controllable circulating systems in small aquaria. These have included both open and closed freshwater systems and closed saltwater systems. As the designs eventually worked out have proved to be entirely satisfactory, and as many colleagues have inquired about these systems, with a view to building similar ones for their own purposes, the details of construction and operation are explained here.

Primarily these systems are the outgrowth of work of earlier years at the old New York Aquarium where much larger, but similar, equipment formed the basis of operations. This equipment itself had been developed from schemes used by older institutions of similar kind. Naturally, many persons had a hand in developing the arrangements and devices employed at the New York Aquarium. For these reasons the origins of the devices were not always clear, but those chiefly interested and responsible for them at the Aquarium were C. W. Coates and the late C. H. Townsend, and H. Knowles. Townsend (1928) and Breder & Howley (1931) reported on some of these features. It has been found that by suitable modification of the principles of the larger devices it is possible to develop very useful miniature equipment. Such need, of course, applies only to laboratories not connected with large public aquariums and which consequently lack the utilities usually only to be found in such places. These devices have been worked out in connection with experimental work carried on in the laboratories of the Department of Fishes and Aquatic Biology of the American Museum of Natural History, which has been supported in part by the National Science Foundation.

Open Systems

An "open system" as here used refers to one in which the water is used but once and not recirculated. That is, there is only a supply line and a drain line. This calls for little comment in present connections except where a very small, well-regulated flow is required. Such apparatus may be arranged to provide as little as a specified number of drops a minute, and will maintain a surprising accuracy if properly designed.

The overflow provided for this system is a constant-level syphon. If such a syphon is made by a glass blower it is expensive, subject to breakage and is not readily cleaned. Syphons can be quickly and cheaply made of some straight glass tubing, a tee, some flexible rubber or plastic tubing, and two small pieces of wood or plastic strip. No dimensions are given, as these will vary with the individual needs, although Text-fig. 1 is drawn to scale. The two pieces of plastic are identical and should have two holes drilled in them that will snugly fit the glass tubing. These parts are then assembled to make a constant-level syphon attached to the lip of an aquarium as shown in Text-fig. 1 and Pl. I, Fig. 1. The lower piece of plastic may be fastened to the aquarium by small clamps or be cemented to it. The open, upper end of the tee vents the syphon. If a cap or plug is placed on this it immediately becomes a simple syphon and will drain the aquarium to the level of its inlet tube. This is sometimes found to be an added handy feature. The level of the water in the aquarium will be that at which the overflow water spills out through the horizontal leg of the tee. Adjustments of this to a fine point may be made by raising or lowering the tee through the hole in the plastic support, or this whole external assembly may be moved up or down by altering the position of the straight length of tubing which passes through the hole in the other piece of plastic connecting it with the tube in-

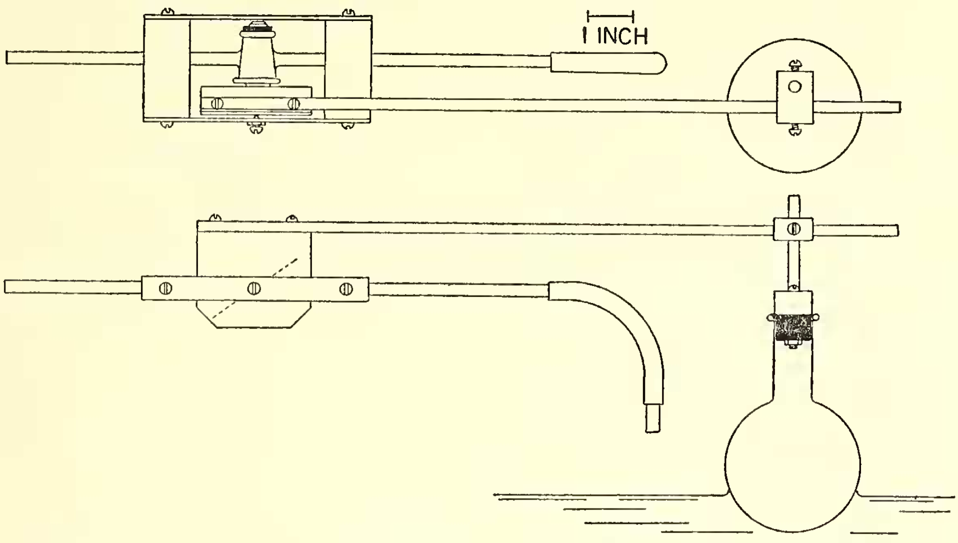


TEXT-FIG. 1. Side and end view of constant-level syphon made up of standard parts.

side the aquarium. By arranging the outside part of the syphon to lie along the aquarium wall, as shown, the danger of its being in the way of operations is reduced. It is obvious that cleaning presents no problem with this type of syphon. In most cases a plastic or glass strainer is placed over the intake end of the syphon. If something does nevertheless block the syphon tube from the aquarium, it almost always can be cleared by blowing into the open end of the tee and restarting the syphon by drawing on this same open end of the tee while the outlet tube is held shut. It is possible and sometimes more convenient to attach the outer portion of the constant-level syphon to a small board which is affixed to a pivot at its upper end so that it is free to rotate on the stationary part attached to the aquarium frame. A small handle pointing upward from there makes its adjustment simple and marks on the latter in reference to some stationary part make return to a former rate of flow exactly possible. The action is simply that by rotating the part of the syphon so that the horizontal part of the tee raises or lowers, the level in the aquarium follows accordingly. This in turn affects the float valve, which is described below. The rate of flow will increase if the syphon outlet is lowered and decrease if it is raised. This is useful where the exact level of water is not of any importance but where it is desired to vary the amount of water flowing through the aquarium by specific amounts and where it is necessary to repeat such changes in flow at will.

If the water supply has considerable pressure, such as is ordinarily encountered in city water systems, or approaches it, a pressure-reducing valve which may be regulated should be employed. This can bring the pressure down to a value which will not burst or otherwise destroy the light equipment to be employed. This valve placed someplace in the supply line should be set so as to deliver little more than the maximum amount of water which will be required of it. Another way to accomplish the same purpose is to permit the supply water to run into a small reservoir of no more than sufficient height to provide enough head of pressure. Into this reservoir the supply water is allowed to run continually, of a little more volume than the aquaria will ever need. This is necessary to maintain a constant head in the reservoir. A small excess will overflow and go to waste by this method. It is economic only where water saving has no significance.

The water flowing into this aquarium is controlled by a float-valve constructed of a glass stop-cock, a suitable-sized chemical flask and some small parts of either wood or plastic. These are assembled as shown in Text-fig. 2 and held together by iron screws and two pieces of strip steel. This metal is mentioned because of the danger of toxic salts forming if brass were used, since such corrosion might fall into the aquarium. A one-hole cork is bolted to a piece of lucite and then inserted into the mouth of the flask as shown. A dowel or plastic rod is inserted in the other hole in the plastic piece and secured.



TEXT-FIG. 2. Top and side view of float-valve for control of inflow of water and additives.

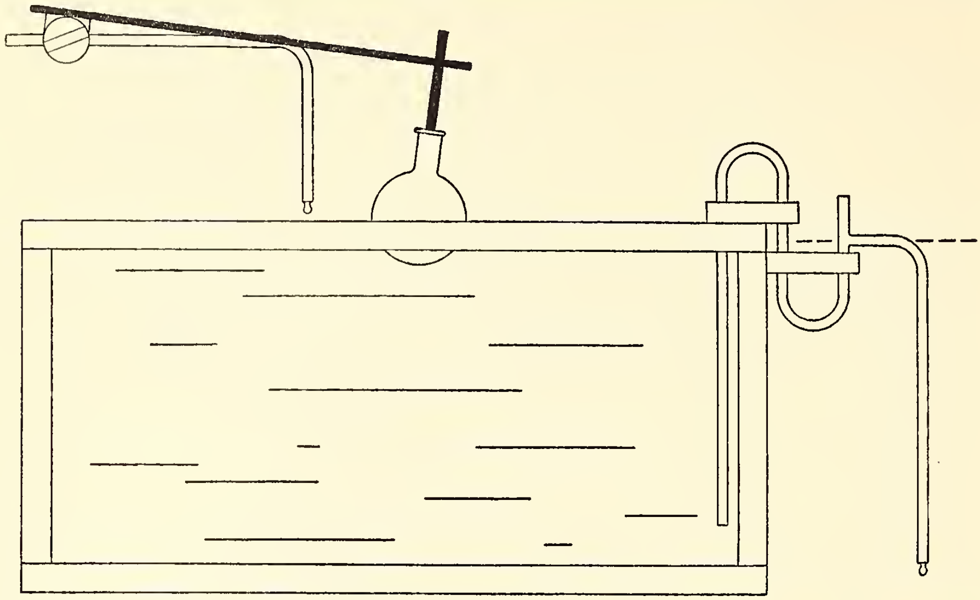
A similar piece of plastic is movably secured on this rod and on a similar one at right angles to it, extending from the valve. This is so arranged that the center of the flask comes to rest directly below the horizontal rod extending from the valve. This is best seen in the plan view of the device. By loosening the two set screws in the upper plastic piece the flask may be moved vertically on the one and horizontally on the other. Pl. I, Fig. 2, shows one arrangement of this device.

The extending glass tubes which are an integral part of the stop-cock are inserted through two snug holes in the wood or plastic end-pieces of the valve and these are held in position by the two steel strips which are held in place by four wood screws. In the center of one of these steel pieces a hole is tapped into which is screwed a set screw with a pointed end (about 60°) and a lock nut as shown. The stem handle of the stop-cock is imbedded in a piece of wood cut about as shown. For this purpose a suitable space is hollowed out in the block into which the stem is inserted, the space around being filled with plastic wood or similar product. The face of the block and the stop-cock stem must be at right angles. On the outer face of the block a small steel strip is affixed with a small drill-tip impression at its center on the axis of the stem. Into this the pointed set screw fits as shown. This is adjusted so that the valve works freely without being too tight or leaking. This prevents the glass stop-cock from working loose and leaking after a time of long-continued operation. The diagonal dotted line on the block indicates the position of the hole through the plug as well as that of the handle on the stem. It is shown in a position just fully closed. It is obvious that with a fall in the water level the valve will open proportionally to the change in water level and shut itself off as the water level rises.

The interaction between the constant-level syphon and this valve is indicated in Text-fig. 3. It is clear that danger from flooding could come only from some damage to the equipment. If, for instance, something clogs the overflow in any way, the float valve shuts itself off when it has reached whatever predetermined point for which it has been set.

As an extreme point of precaution a safety alarm or shut-off could be built as an entirely separate system. Such a device, which has never failed so far as the writer's experience goes, consisted of an old pair of contacts such as are to be found on relays to one member of which was fastened a shell vial. This hung over the water in such a manner that when the water rose over a specified place it lifted the vial and pushed the two contacts together. It operated on two dry cells to ring a doorbell but could be used with a relay to switch on house current to operate any suitable device. This could be a normally open solenoid valve placed in the supply line. Such extreme caution would only be warranted where a little flooding would be disastrous.

It is obvious that this float-valve could be used under certain experimental procedures to add chemicals to an aquarium at a prescribed rate by inactivating the float and fixing the rate of flow by hand. It also could be used to bring the concentration of some chemical to a fixed limit and then hold it at that point in flowing water



TEXT-FIG. 3. Diagram of interaction between float-valve and constant-level syphon. Dashed line represents level of water in aquarium and syphon arm.

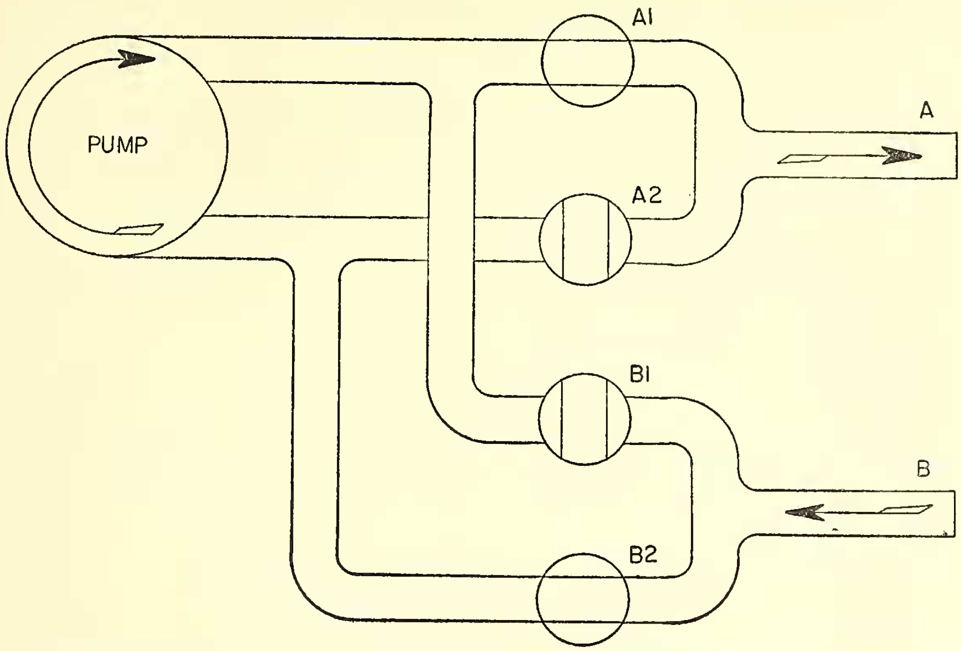
aquaria. The water supply would operate as above described and a second float-valve regulated to add much less chemical than the water flow would move with it and act as a follower to the other if there was any fluctuation in the flow of water, thus holding the additive in proportion to the change of water. Also a single float could be arranged to operate the two valves in proportion to the setting of each.

While the designs of these float-valves have varied from time to time, all have been built embodying the same principles as herein described. The first and somewhat primitive one has, at this writing, been in service continually for more than four years and is still entirely satisfactory and dependable.

CLOSED SYSTEMS

The term "closed systems" refers to circulating systems in which the water is returned to the aquaria after filtration or other treatment and none is allowed to run to waste during normal operations. Some such system is mandatory for the maintenance of marine forms remote from a ready supply of sea water, and often convenient or necessary for various experimental procedures involving freshwater aquaria. This is especially true of cases where it is necessary to maintain close control of some feature such as temperature, chemical quantities and the like. By use of such means it is possible to maintain a series of aquaria with absolutely identical water conditions, as the water in all is part of a common body. Consequently no matter what transpires in one aquarium there is no opportunity for the water of that one to depart from the characteristics of the rest since it is moving freely from one aquarium to the other and is being continually and effectively mixed.

An especially useful arrangement for some purposes is one in which the flow between aquaria may be continuously varied from maximum in one direction through zero flow to maximum flow in the opposite direction. This may be readily accomplished by the adjustment of four valves while the pump runs continuously in one direction at constant speed. The details of the arrangement of these valves are shown diagrammatically in Text-fig. 4. Pl. II, Fig. 3, is a photograph of such a device. In operation the action is as follows. With valves A2 and B1 closed and the others open, the flow is out through pipe A and returns through pipe B, as indicated by the arrows, at maximum flow. If these valves are reversed so that A1 and B2 are closed and the others open, the flow through pipes A and B is reversed, although the flow through the pump remains as indicated by the arrow on it. To pass uniformly from the first position, as shown in Text-fig. 4, through a state of no flow to the reverse, either valve A2 or B1 can be gradually opened. This reduces the speed of water movement because of "back leakage." After one of them has been opened fully the opening of the other can further retard flow. When it, too, has been fully opened, that is with



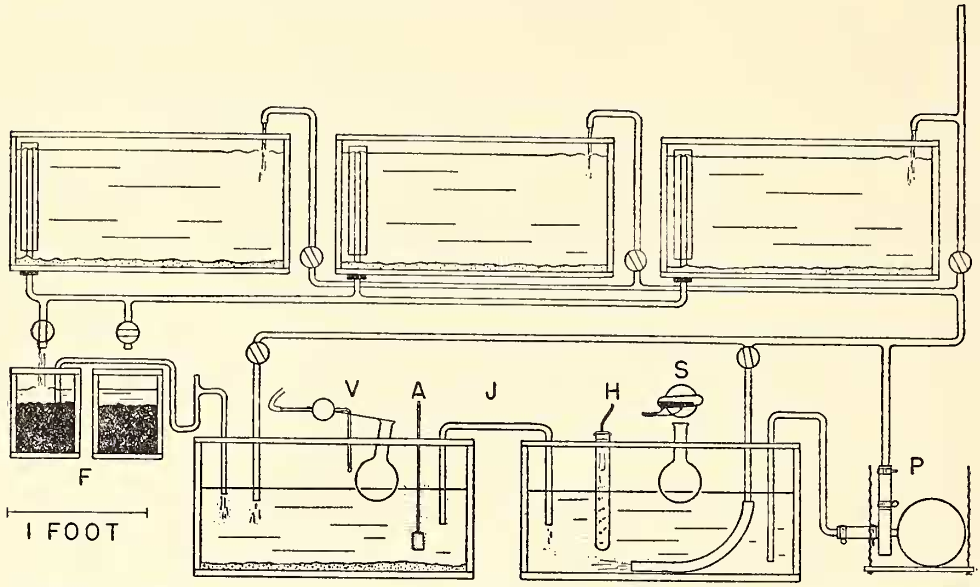
TEXT-FIG. 4. Diagram of piping and valves for continuously variable flow from maximum in one direction through zero flow to maximum in the opposite direction.

all valves fully open, there should be no flow through pipes A and B, as there is as much pump pressure in one branch of both A and B pipes as in the other. Then by beginning to close either valve A1 or B2 the flow begins to move in the opposite direction. When these two are fully closed, the maximum flow in the opposite direction has been reached.

If three valves are arranged on either line A or B or such a set on both, various water treatment devices may be placed in the series, such as a heating or cooling device, in which case the water may be best passed through a glass coil for heat exchange purposes. This arrangement could equally well be used for any kind of decontamination which might be required or for the introduction of specified materials being mixed with the passing water. Unlike most aquaria plumbing, in this case the water must pass from one aquarium to another, so that as many as may be needed can be placed in series.

A diagram of a more usual arrangement for a closed circulating system is shown in Text-fig. 5. This is the form which is perhaps most useful for general laboratory purposes. Here each aquarium is respectively supplied and drained directly from a common supply and return. It is advisable to use a pump of somewhat greater capacity than needed for the purpose. With this means the excess water can be returned to the reservoir without passing through the aquaria, which greatly assists in the efficient application of whatever water treatment is being given and insures adequate pressure for the system. Simple filters may be made by wedging a piece of glass in a small aquarium and filling the intake side with suitable filter material, while the reservoir may be used for whatever chemical or other treatment is to be applied. Two may be provided, as shown in the figure, and used alternately or together. A constant-level syphon takes the water to the first reservoir aquarium. Only one syphon is shown, which may be switched to the other aquarium for cleaning purposes.

The pipes and fittings used in this system are standard hard rubber. Connections between aquaria at the same level may be made by "jumpers" which are preferably of hard rubber. Their use is indicated in the lower level aquaria shown in Text-fig. 5. These have been found to be fully satisfactory and in several years' operation have not clogged nor have they become airbound. They are, however, not suitable for the overflow lines of the upper series of aquaria. Here constant-level syphons may be used as shown in Pl. I, Fig. 1, or, preferably, a hole may be drilled in the slate bottom of each aquarium and a one-hole rubber stopper holding a glass tube inserted. Still better is the installation of a hard rubber standpipe locked in place with fittings. The drilling of slate is not easily accomplished and there is considerable danger of



Text-fig. 5. Diagram of arrangement of a closed circulating system suitable for small marine aquaria. A = aeration outlet. F = filters. H = heater and thermostat. J = jumper. P = pump on hanging support. S = safety cut-off switch. V = float-valve. Distilled water supply carboy not shown.

cracking or otherwise damaging the aquarium. The manufacturers will supply aquaria with such holes drilled on order.

Since the supply to the aquaria of this system is preferably from the top, as indicated, the drain line as above described may be made to draw water from the bottom of an aquarium by the following simple means. A tube of glass, or other material, of larger diameter than the drain tube and as long as the depth of water in the aquarium, is placed over it, reaching nearly to the bottom of the aquarium. Since the larger tube extends above the surface, water leaving the aquarium must enter the annular space between the two tubes and pass up between them to spill into the open upper end of the inner tube. In addition to giving the aquarium a better circulation, much detritus is drawn up through this arrangement and delivered automatically to the filters. The outer tube, if of glass, may be positioned by slipping a short piece of plastic tubing on its lower end and cutting various openings or notches in the plastic. The area of these passages should of course be at least equal to the cross-section area of the inner tube. The annular space between the inner and outer tubes should also have this much area, at least. On the other hand, it is best not to make the annular space much larger than needed because this will cause the water flowing through it to move with less speed. The value of this arrangement as a detritus remover is thus lessened, for the slower-flowing water will not lift as heavy particles as will the faster.

As such a system is usually intended to be operated continuously for long periods without attention, a safety feature may be built in which would shut down the pump if the water in the reservoir rose too high or fell too low. The one in current use, shown in Pl. II, Fig. 4, was improvised from the tube of a mercury switch. This was mounted on a rotatable glass shaft running through a support of plastic. It was actuated by a chemical flask float by means of a thread over a small drum so that the motion of the float was transmitted to the pump switch. Any unusual change in the water level, either positive or negative, would indicate some radical failure at some point in the system. Since the aquaria which held the fish were drained by an overflow they would continue to hold their water level so that stopping the pump would insure the retention of water there. Even if one of the aquaria leaked and lost its contents the others would not suffer by draining through the system to it because of this protective device.

To prevent normal evaporation from stopping the pump, a supply was provided which operated in conjunction with the protective switch. This supply was administered by a float valve identical with that shown in Text-fig. 2. A very nice adjustment was found possible with these two float-actuated mechanisms, so that the dripping from the float-valve supply became directly proportional to the evaporation, without at any time tripping the protective cut-off float-valve. On very humid days it could be seen that the number of drops per minute was notably less than on a clear dry day when evaporation was high. In the case of saltwater aquaria this device had an added important application which is discussed under the treatment of salt water.

Because of the nature of the controlling devices above described, it is necessary to observe certain details in starting the system. The levels of water in the lower series of aquaria will be different when the pump is not running than when it is in operation. This is mostly because the drain lines of the upper series of aquaria empty themselves into the lower aquaria when the pump is stopped. Therefore the water is carried at a lower level in these aquaria so that there will be no overflowing when the circulation has been stopped. For this reason a switch should be shunted around the cut-off float to be used in starting the system before the operating level is reached. It will not suffice to wedge the float into a position where its switch will be closed, because its free action is necessary to establish its proper level of operation. After a dynamic equilibrium has been achieved by adjusting both the cut-off device and the density control device, the shunt switch should be opened, after which the system should control itself. If it does not at first, very obvious adjustments of either or both will bring them into the proper relationships.

The diagram of the closed marine circulating system shown in Text-fig. 5 employed seven aquaria for holding experimental fishes, only three of which are shown in the illustration. Three "reservoir" aquaria were used, of which only two are shown. These were standard commercial aquaria measuring 2′ × 1′ × 1′. The two smaller, used as filters measured 10″ × 8″ × 6″. The pump was driven by a 1/10 hp motor and was rated at 10.8 gals. per min. at zero head. The pipe sizes are not indicated, as they would naturally vary with the needs of each system. In this one the flow was slow but sufficient at about three gals. per hour through each of the seven top row aquaria. At the right of Text-fig. 5 the supply pipe is extended upwards for some distance and with the upper end open. This permits building up whatever head of water is desired without subjecting the pipe to pressure greater than that produced by gravity.

Although the upper series of aquaria were intended for holding fishes and the lower series were regarded as treating reservoirs, the latter too may be, and have been, used to hold fishes, that is, all but the one from which the pump draws water, since the suction and turbulence here would be destructive to most small fishes. Aerating stones and a standard aquarium glass heater and thermostat comprised the rest of the water-treating equipment. The heater which turned off when the water reached 74°F. was sufficient to keep the water throughout the system close to that temperature as it was only slightly higher than the normal room temperature. It was found that the aerating stones made it possible to permit the flow of water in the lower aquaria to run through submerged pipe outlets and thereby reduce the amount of splashing and consequent salt deposits. This was not found necessary in the upper series, for each supply pipe carried only one-seventh of the flow in the lower pipes.

Materials

It is strongly recommended for all the purposes for which these devices were developed that only hard rubber or some biologically inert plastic be used. In fresh water, iron plumbing is adequate for many purposes but for sea water no metals whatever should be used if any degree of satisfaction is to be obtained. Hard rubber and acrylic resin or vinyl chloride-acetate copolymer plastics have been used throughout for those parts which come in contact with the water, including the pumps.[1] Also it is important to see that no brass or other such metals are used in positions over the aquaria in order to prevent possible corrosion falling into the water.

In all cases involving the use of pumps for aquarium purposes it is best to have a spare stand-by duplicate pump and motor unit as a precaution against the failure of either motor or pump. It is then possible to change such a unit in a few minutes, in the case of accident, with no serious interruption to the operation of the system. It is most convenient to use flexible connectors between the pump and the rigid plumbing leading to the aquaria. It is then only necessary to unfasten two screw clamps and insert the new unit in place. This type of arrangement is shown in Pl. II, Fig. 3.

An additional advantage of this kind of connection is that it dampens any vibrations, from the pump or motor, which tend to travel throughout the system along rigid connectors. The pump in Pl. II, Fig. 3, was suspended by

[1]In the systems described, the plastics used in the construction of the apparatus go under the trade names of Lucite and Plexiglas and the tubing under the name Tygon. The pumps have been supplied, complete with motors, by Broadbent-Johnston, Inc., Compton, California.

four light cords, a means which is also very effective in quieting such small machines.

Treatment of Water

The treatment of fresh water for aquarium purposes is too well known to warrant comment in present connections and is usually necessary only under special situations. The maintenance of sea water in a satisfactory condition is quite another matter, however. It is not the purpose here to discuss the theoretical aspects of the chemical and physical conditions of sea water. Such matters may be found extensively treated by Sverdrup, Johnson & Fleming (1942) and Harvey (1955). The following is intended purely as a guide for the practical application of principles which have been found adequate to maintain a variety of marine fishes. Under this treatment regular reproductive behavior was quickly established in both *Histrio* and *Bathygobius,* which had been reared from juveniles. It also permitted a variety of volunteer algae and microorganisms to establish themselves. Incidentally these aquaria were kept under conditions of no daylight, the illumination being supplied by fluorescent tubes of the "warm white" type necessary for satisfactory plant growth. The periods of light and darkness were controlled by a time switch.

The equipment found necessary for the control of sea water consisted of a small hydrometer, a colorimetric pH device and some simple titrating equipment.

The filters were provided with bone charcoal and the bottoms of the aquaria and reservoirs were floored with so-called coral sand, and aerating stones were placed in various convenient places, but not in the aquaria containing fishes.

The specific gravity and pH were taken every day until the rate of change was established and from then on were taken at less frequent intervals. This rate of change will vary with the quantity of water, the bulk of the organisms contained and the temperature of the water. At less frequent intervals titrations were made to determine the variously-called excess base, titration alkalinity, or alkaline reserve. This method, which measures the bound CO_2, is not especially accurate but is sufficient for the present purposes. It consists of titrating a sample with N/100 hydrochloric acid to which brom-cresol purple has been added as an indicator. After the purple color has vanished the sample is repeatedly boiled and further titrated until the purple color no longer reappears on heating. If the sample consists of 100 cc. to which five drops of indicator have been added, the final burette reading in cc. multiplied by 0.1 gives the bound CO_2 or bicarbonate in millimols/liter. This method is not to be generally recommended for accurate work but is sufficient as a comparative measure of how far and how fast the aging water is departing from its original value.

With this information, corrective measures may be taken. The specific gravity is nearly taken care of by automatic means involving the use of the float-valve already discussed. Under normal operations distilled water is used to make up for the evaporation of sea water, which of course tends to increase its density thereby. This has been satisfactorily supplied from a five-gallon carboy on a shelf higher than the float-valve. The operation of the float-valve holds the amount of water in the system at a constant volume, which means also that the dissolved salts will remain at a constant amount. If it is desired to increase the density of the water, instead of using distilled water as an additive, sea water may be used until the specific gravity has reached the desired level. If it is desirable to reduce the salinity, water may be withdrawn from the system while distilled water is used in the float-valve supply. This may be conveniently accomplished by means of a syphon with a small hose clamp so that the flow is restricted to a drip slow enough to permit the float-valve to follow. Although distilled water was customarily used, in its absence tap water was used with no detectable effect on the fishes or the system.

If the pH falls to lower values it may mean that there is an increase in the amount of free CO_2 present. This could indicate too many organisms for the volume and temperature of the water or too much decomposition for the anti-acid components of the system to dispose of rapidly. The calcium carbonate in the sand should react with the acids formed and unless there is overcrowding this type of decreasing alkalinity usually does not present a problem. If the placing of fresh activated bone charcoal in the filter results in an abrupt increase in the pH, it is almost certain that there is too much free CO_2 present. The use of charcoal renewed at short intervals will bring the CO_2 content down but the charcoal rapidly becomes saturated and cannot be thought of as a regular part of the regulatory process. An increase in the number of aeration stones or amount of air they pass, while much slower in its effects, is a much more satisfactory way to insure against the accumulation of CO_2.

If on a falling pH, none of the procedures above mentioned increase the pH significantly, the titration reading should be carefully checked and it too should show a decrease. This would indicate a lowering of the bound CO_2 which does not normally occur in an unoverloaded system in the presence of calcareous sand. If it does, however, more sand may be added, or sodium bicarbonate may be dissolved and administered with the distilled water through the float-valve. Since the sand alone tends in a long-term sense to disproportionately increase the Ca in solution as compared with the Na, the occasional use of sodium bicarbonate, which tends to do the reverse, aids in keeping these two quantities in more nearly normal proportions. See Breder & Smith (1932).

The described procedures may seem to be somewhat complicated, but they are, in fact, not much more complex than those involved in maintaining a similar number of standing freshwater aquaria. After the equipment is built and regulated, so that valves and controls are in balance, there is nothing to be done with them at any time and in fact there should be no tampering with them at all. It is probably wise to post warnings to this effect. There is little aquarium cleaning to be done, as most of the accumulating detritus is automatically deposited in the filters. Aside from feeding the fishes and sometimes cleaning algae off the glass sides, the latter being controlled by adjusting the lighting arrangements, there are the following routine matters to be done. These will vary with each installation but may be approximated by the regimen under which the described installation of seven aquaria were controlled, as follows.

Read pH and Sp. G	Twice a week	5 min.
Titrate sample	Once a week or less	15 min.
Fill distilled water carboy	Twice a week	5 min.
Clean filters	Once in 2 weeks	15 min.
Make adjustments based on above information	Once a month or longer	Various

The need for changing the pump and motor is such a rare occurrence as not to figure in the above schedule and should not take more than 5 minutes. Every attempt has been made to reduce the maintenance of the system to its minimum. It is not uncommon for the system to be left alone for as long as three days, as over a long week end. The only thing to normally expect at the end of this period is some extra-hungry fishes. It should be borne in mind that the smaller the system—that is, its total amount of water—the more rapidly decomposition or contamination can spread through it. It is prudent not to reduce the size of the equipment more than necessary.

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EXPLANATION OF THE PLATES

Plate I

Fig. 1. A constant-level syphon in operation.

Fig. 2. Float-valve for the control of inflow. Note: This is the arrangement as used in the closed saltwater system. The placement is for convenience, but usually valves are placed close to one end.

Plate II

Fig. 3. Pump provided with reversible flow device. The plastic pump here shown is powered by a 1/80 hp motor and is rated to deliver 3.7 gals. per min. at zero head.

Fig. 4. Safety control for closed circulation. Its relation to the system is indicated in Text-fig. 5. The pipes at the extreme right are the pump intake and excess return.